PREDICTIONS OF FUTURE PV CAPACITY AND CO2 EMISSIONS' REDUCTION IN THE US

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ABSTRACT

The MARKAL-MACRO (USMM) integrated energy-environmental-economic model was used to simulate the US energy capacity for the next 30 years. Photovoltaic technologies were assumed to compete on cost alone with 200 other technologies in the US, in a deregulated environment. Its was shown that PV can become cost-effective in both distributed and central power applications in the US, if current expectations of performance and cost reductions materialize. The predictions of this analysis compare well with the goals of the US Photovoltaic Industry Roadmap and industry learning curves. Capacity constraints and possible deviations from expected performance/cost goals are discussed. It is shown that it is important to maintain high growth rates in the next few years to achieve the Roadmap goals over the long term.

1. Background

There are several models in use for integrated energy-environmental-economic analyses of the future US energy outlook. The Energy Information Administration (EIA) of the DOE uses primarily the National Energy Modeling System (NEMS) for such forecasting. Another model used by the US-DOE Policy Office and 35 other countries is MARKAL-MACRO (USMM). The two models were compared by Morris et al., [1], using the AEO assumptions for performance and cost in the future 20 years. The comparison entailed the whole electric supply sector in the US, electric generating capacity, primary energy use, carbon emissions and price of electricity. It was shown that there were only minor differences between the two models in their projections for renewables. Under the AEO cost and performance assumptions, neither PV nor wind would reach high penetrations in the US energy market within the period 2000-2020 [1]. In this paper we present predictions for PV and wind penetration produced my MARKAL, under the more optimistic cost/performance assumptions produced by EPRI [2]; these are shown in Table 1. It is noted that the PV industry's learning curves support the EPRI assumptions. Today's (2001) prices are an anomaly in these learning curves as the California energy crisis and cost incentives created a demand that exceeded supply and subsequently high PV prices. We expect, however, that as supply catches up with demand prices will go down.

2. MARKAL simulations using the EPRI Data

MARKAL is a demand-driven, multi-period, linear programming model optimization model. MARKAL establishes a competitive market to supply energy demands. All energy resources and both supply and demand technologies compete in this market in an even-handed manner.

In order to maintain realistic estimates, constraints were used in MARKAL for PV and the technologies that we found to be the major competition to PV (i.e., wind, microturbines and advanced combined cycle plants). We conducted simulations with growth rate constraints of 25%/year, 30%/year and 50%/year. It is noted that the PV Industry Roadmap forecasts a 25%/year average growth for the industry over the period of 2000-2030. The PV penetration results of these simulations are shown in Figure 1 together with the PV Industry Roadmap forecasts for distributed and grid (wholesale) generation. In these simulations we assumed that all distributed generation is grid-connected (e.g., through reverse metering) and therefore, subject to the same economic competition as the grid wholesale generation. We also assumed that the price of distributed generation is the same as that of central generation, listed in EPRI (1997). The Roadmap forecasts that 1/3 of the new domestic installations will be DC and AC value (niche) applications which are not grid-connected, and therefore, are not included in this analysis. As shown in Figure 1, the PV penetration predictions generated by MARKAL are similar to the Roadmap forecasts. It is further shown that it is important to maintain high growth rates (i.e., 30%/year) for the next 5-10 years to achieve the Roadmap goal of 25%/yr over the 2000-2030 period.

Figure 2 shows the displacement of carbon emissions resulted from PV penetration under the three growth rate constraints. It is shown that the predicted emission displacement is slightly lower than what is forecasted in the Roadmap. Figure 3 shows a comparison of PV penetration with the penetration of the strongest competitors, which are wind, microturbines and advanced combined cycle turbines. The total of the later two is shown as "turbines". It is shown that Wind 5-7 technology, corresponding to installations up to 10 miles away of the grid, becomes cost competitive with conventional energy generation technologies early in the considered period [2]. The MARKAL results show wind reaching the maximum availability of 100 GW [2] by the year 2015. Wind-4 installations which carry a higher transmission cost than Wind 5-7, do not enter the picture within this period. Although the capital cost of Wind-4 installations is lower than that of PV, wind installations have a higher operating cost and do not contribute on peak shaving as much as PV does.

MARKAL generates electricity prices through its shadow price. MARKAL seeks a least-cost solution, which approximates a competitive market. NEMS/AEO assumes a competitive market in states that have substantially adopted competitive pricing, an average of competitive pricing and traditional cost-of-service pricing in states with mixed pricing structures, and cost-of-service pricing in states that have not adapted competitive markets. In newly deregulated markets, electric prices have gone very high during peak hours, when there was a shortage of capacity. Sioshansi[3] reports a recent price of $287/MWh in the Pacific Northwest West, which is dramatically higher than historical norms. Peak periods usually coincide with hot sunny days, when PV has its highest potential. For purposes of this analysis, we assumed that PV matches the peak load period. MARKAL characterizes the electric load curve in three seasons (winter, summer, intermediate), night and day, and peak. To determine the potential role of PV for peaking in a deregulated environment, we artificially narrowed the time-period for the summer day, inducing a high cost peak ($200-$300 per MWh). The results indicated that continuing conditions of high peak pricing are extremely favorable to PV.

DISCUSSION

Integrated energy-economic-environmental modeling demonstrates that PV technologies have the potential to compete with conventional sources of electricity generation, if the current expectations of cost and performance improvements materialize. MARKAL results forecast a PV based grid-integrated capacity of about 10 GW in 2020, growing to 100 GW by 2030. These predictions are based on cost alone without assigning any credit to PV for reducing CO2 emissions in the US. Nevertheless, the said PV penetration would reduce carbon emissions by over seven million metric tons in the year 2030 alone**.** If the current dramatic raises of peak electricity prices continue in the long term, PV can reach the 100 GW levels by the year 2015. Studies aiming to describe the impact of financial credits in distributed PV and the value of avoided material replacement in new roof and facade applications are ongoing.

REFERENCES

[1]Morris et al, NEMS and MARKAl-MACRO Models for Energy-Environmental-Economic Analysis, Journal of Environmental Modeling and Assessment, in press.
[2] EPRI-DOE, Renewable Energy Technology Characterization, 1997, http://www.eren.doe.gov/power/techchar.html
[3] Sioshansi, F.P. (2001) California's dysfunctional electricity market: policy lessons on market restructuring, Energy Policy 29: 735-742.

Table 1. Characteristics of Central PV Systems

Year:	2000	2005	2010	2015	2020	2025	2030
Capital Cost: ($/Wp)	6.08	3.33	1.72	1.47	1.27	1.12	1.01
Module efficiency: (%)	7.2	8.8	11.2	12	12.8	13.2	13.6

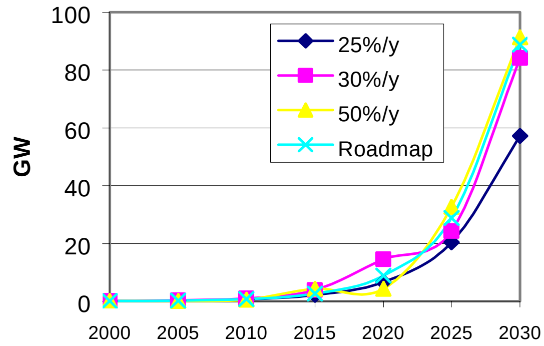

Figure 1. PV Projected Market Penetration

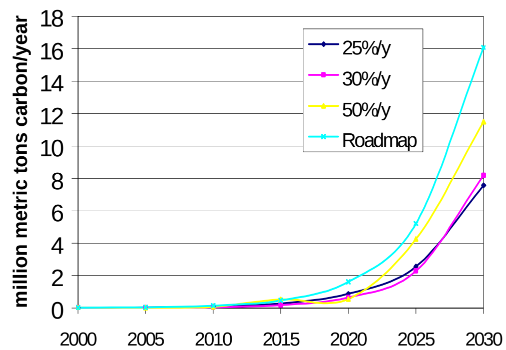

Figure 2. Carbon Displacement

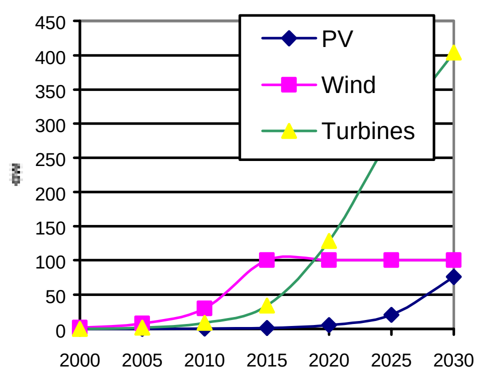

Figure 3. Market Penetration of Competing Technologies Under 30% Growth Constraints